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Effects of spray impingement, injection parameters, and EGR on the combustion and emission characteristics of a PCCI diesel engine

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A B S T R A C T

The effects of spray impingement, injection parameters, and exhaust gas recirculation (EGR) on the combustion characteristics and exhaust emissions of a premixed charge compression ignition (PCCI) diesel engine were investigated using a single-cylinder test engine and an optically accessible engine. Tests were carried out under constant speed with variable injection pressures and EGR rates. Exhaust emissions and in-cylinder pressures were measured under all experimental conditions. Analyses were conducted based on diesel spray evolution and combustion process visualisation coupled with performance and exhaust emissions. Higher injection pressures led to lower smoke, hydrocarbons (HC), and nitrogen oxide (NO_x) emissions but had roughly the same CO emissions compared with lower injection pressures. Higher EGR rates led to the simultaneous reduction in NO_x and soot emissions due to lower combustion temperatures compared to conventional diesel combustion. However, HC and CO emissions increased due to fuel impingement, bulk quenching, and over-mixing, leading to an air–fuel mixture that was too lean to burn. An optimum spray targeting spot was identified, leading to lower emissions of soot, CO, and HC but higher NO_x emissions without EGR. The simultaneous reduction in NO_x and soot was achieved using the optimum spray targeting spot by introducing EGR, which was accompanied by homogenous combustion and a low luminosity flame attributed to fuel impingement on the piston bowl wall.

1. Introduction

With growing concerns about fossil-fuel depletion, environmental protection, and global warming, production engines with higher fuel conversion efficiency and lower engine emissions are urgently needed. Additionally, many countries are implementing stricter emission regulations. Diesel engines are more attractive for powering light duty and heavy commercial vehicles because of their superior fuel economy, durability, reliability, and high specific power output compared to spark-ignition (SI) engines [1]. However, conventional diesel combustion suffers from increased particulate matter (PM) and nitrogen oxide (NO_x) emissions. This implies that newly developed diesel engines must have lower PM and NO_x emissions while maintaining or attaining higher fuel conversion efficiency. To meet the strict performance and emission targets set for engines, new combustion strategies, such as homogeneous charge compression ignition (HCCI), have been widely investigated. HCCI eliminates locally rich-fuel–air mixtures and reduces the combustion temperature, thus simultaneously achieving low PM and NO_x emissions with relatively good engine performance. However, HCCI faces many challenges, including a lack of combustion phase control under different operating conditions, fuels with different properties, high pressure-rise rates under high loads, and limitations in creating homogenous fuel–air mixtures [2].

Different combustion concepts have been developed to control the in-cylinder combustion process, in addition to the use of expensive exhaust after-treatment devices. The concept of employing in-cylinder control parameters, which is considered the most practical, least expensive, and most effective control measure, has been widely investigated. These parameters include but are not limited to injection pressure, number of injections, shape and timing of the injection, boost pressure, EGR, and swirl ratio [3,4]. One of the most promising combustion concepts is an HCCI combustion strategy implemented in modern direct injection diesel engines through partially premixed charge compression ignition (PCCI), where fuel and air are not fully homogenous, but the combustion event can be controlled more readily.

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